Research Essay (70 Points)

Instructions

1. Students will research and write a 500- to 700-word essay on the following topic: "Keeping Our Future City's Infrastructure Healthy: Using Nanotechnology To Monitor City Structures and Systems."

Students will:

a. Select a critical component of their Future City's infrastructure to monitor, such as a levee or power transmission line;

b. Describe how a sensor system built into that infrastructure component would use nanotechnology to check for signs of problems; and

c. Describe how a control system, of which the sensor system is one part, can resolve those problems with minimal human intervention.

Benchmark Your Essay

For information and tips about researching and writing the essay, view the Future City Competition Tutorial CD-ROM. You can also review winning essays from previous years on the Future City Web site, www.futurecity.org.

2. Students should use a variety of sources of information, such as interviews with experts, reference books, periodicals, and the Internet. Students must attach to their essay a list of at least 3 sources upon which the students relied.

3. The teacher or engineer-mentor must complete the Essay Form and submit it with the students' Research Essay and Reference List as directed by the Regional Coordinator.

Documentation Details

List the name of your school and of your Future City on each page of the Research Essay. Place the word count at the end of the essay. Be sure to keep copies of the Essay Form, Research Essay, and Reference List to take to the Regional Competition.

4. The Research Essay Outline is the primary basis (60 points) on which the project will be evaluated and scored. The remaining 10 points are allocated (2 points each) to the Research Essay's organization and clarity; grammar; spelling; word count; and Reference List.

Research Essay Outline

1. Select a component of your Future City's infrastructure to monitor and explain why that component is critical to the health, safety, and/or welfare of your Future City. Examples include, but are not limited to:

a. Structures—dams, levees, public buildings, bridges, and tunnels.

b. Utilities—electric power, sewers, ventilation, and drinking water.

c. Transportation—highways, railroads, airports, subways, and seaports[JME1].

d. Communication—emergency warning sirens, radio receivers and transmitters, and satellites.

2. Define the requirements of the monitoring system

a. Identify potential threats (e.g., flood, fire, or exposure to weather) and explain how they could cause that part of the infrastructure to fail.

b. Decide which variables (e.g., temperature, pressure, or velocity) to monitor and what values would indicate a problem (e.g., oxygen level different than 20%).

c. Determine what should be done when a problem is detected. For example, an alarm will sound, traffic will be rerouted, or an e-mail message will be sent to the engineer. Consider a hierarchy of responses, with the goal of fixing the problem, at least temporarily, with minimal human intervention.

3. Devise a control system that satisfies the requirements in 2c, above, and describe in detail how it works:

a. Is the control system centralized, like a brain, or distributed (e.g., a series of remote control stations that communicate with a central controller and primary server or control console)? Is it totally automated or does it require human intervention or oversight?

b. What kinds of sensors are used? How do they interface with the infrastructure and by what means do they communicate with the controller when the value of any of the variables being monitored falls outside the acceptable range?

c. When it receives input from the sensors about a problem, how does the controller decide what action to take and communicate with other devices (actuators) to trigger the appropriate response?

d. How does the actuator automatically initiate the corrective action or signal the need for human intervention?

e. How is nanotechnology used in the control system design? In particular, how is

nanotechnology applied to the sensor design? Is nanotechnology used in any other parts of the control system? What is the advantage of using nanotechnology?
f. Discuss the role that a specific type of engineer (i.e., chemical, civil, electrical, or mechanical) would have had in designing and implementing the control system.

Be Creative!
In the future, nanotechnology will be essential to implementing structural health monitoring systems. To[JME2] maximize your score, be sure to take full advantage of that technology in designing your structural monitoring control system; i.e., not only in the sensor devices embedded in the infrastructure but also in the controller(s) and/or actuator(s).

What is Structural Health Monitoring?

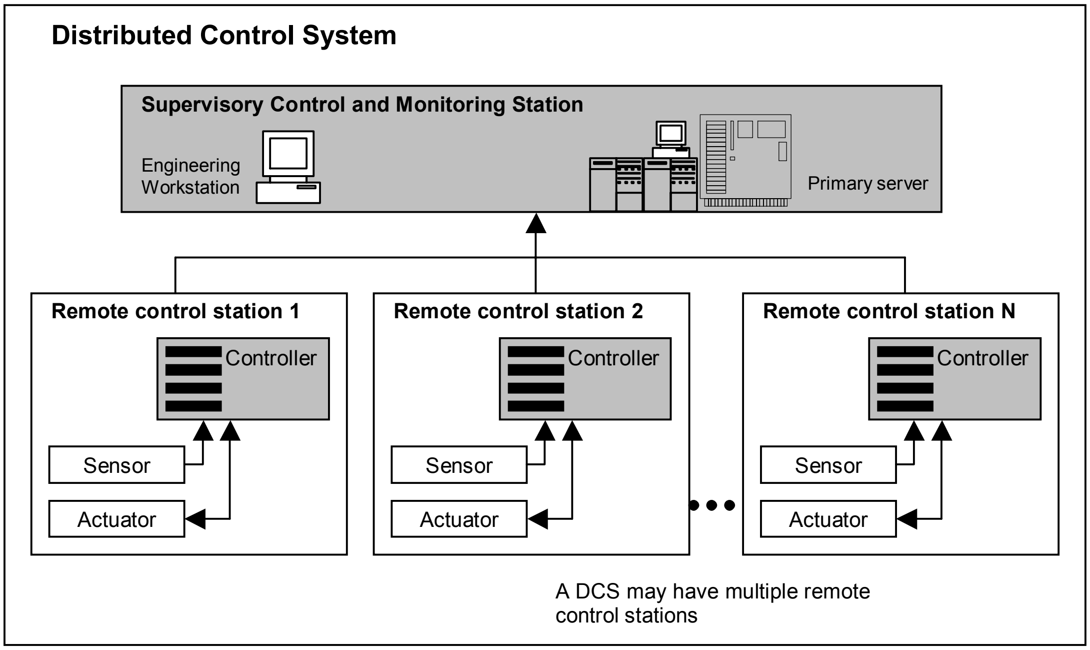
Just as a doctor monitors the condition of your body by checking your skin, lungs, and blood chemistry, an engineer can monitor the condition of a city's infrastructure by checking for cracks, congestion, and contamination. And just as a doctor, upon finding a medical problem, will try to diagnose and treat it, the engineer, upon finding a problem, seeks to mitigate or repair it. What kind of problem might it be? It could gradual, as the weakening of a viaduct due to erosion around the piers, or sudden, as the failure of a levee caused by storm surge. It may be relatively easy to fix, as removing a tree that has fallen across a road, or resource-intensive, as when a tunnel collapses.
With a monitoring device (**sensor**), the engineer seeks to detect a problem before significant harm is done. For example, a carbon monoxide detector can show if the air in a tunnel is nearing an unsafe level for people driving through.
But gathering information with a sensor is just the first step in protecting the infrastructure. The data must be communicated (e.g., by sending electrical impulses along a wire) to a person and/or device (**controller**), which decides what to do and tells (e.g., by transmitting radio waves to a receiver) other people and/or devices (**actuators**) what action(s) to take to achieve the intended outcome.

How Control Systems Work

Working in concert with any necessary human involvement, the sensor, controller, actuator, and communication hardware comprise the **control system**. The processes governed by the control system may be as simple as turning on a streetlamp at dusk or as complex as monitoring a car's on-road performance, from engine to tailpipe.

Examples of Common Control Systems
1. Thermostat (e.g., for an air conditioner)—The user specifies a desired temperature, and the sensor (thermocouple) signals the controller when the temperature is outside the preset range. The controller sends a signal that turns on the heating or cooling element. When the sensor indicates that the temperature is back within range, the controller turns off the heating or cooling element.
2. Traffic Light—An emergency vehicle such as a fire engine emits a signal when approaching a traffic light. The sensor, when it detects the vehicle's signal, communicates with the controller, which, in turn, sets the traffic light green for the direction of the emergency vehicle and red for the other directions.
3. Toilet—The user depresses a lever that opens the trap, flushes the toilet, and releases water from the tank into the bowl. When the tank is drained, the valve closes and water is first let into the bowl and then into the tank. A float in the tank rises with the water level; when the sensor indicates that the tank is full, the flow is shut off.
4. Car Airbag—Accelerometers (microgyroscopes) sense a rapid acceleration in excess of the normal range for driving and send a signal to deploy the airbag.

The following figure depicts a **distributed control system** (**DCS**), which is a network approach to managing a large system (e.g., the HVAC [heating, ventilation, air conditioning] system in a city government building). In this example, the controllers are not all in one central location (like a brain) but are distributed among a number of remote stations.
Note that this system is networked for communication and centralized monitoring by humans. The controller (computer or processor) is each remote station receives data from input modules (sensors) and sends data to output modules (control equipment or actuators). Computer buses or communication networks (hardwired, public nets, or wireless) connect the remote stations to each other, as well as to the central controller and primary servers or control consoles.



What Is Nanotechnology?

Nanotechnology involves the creation of materials, devices and systems through manipulating matter at the nanometer length scale (1-100 nm). This means that scientists and engineers are working with items much smaller than molecules, essentially atoms. The final object that they create does not have to be nanoscale, it can be much larger (micro or macro size). What is important is that it takes advantage of the novel properties that arise because of the nanometer length scale. For instance, nano-materials have a much larger surface area relative to their volume which makes them extremely strong and resilient. Interest in nanotechnology dates from the 1950s. At that time, physicists were focusing on nuclear reactions and atomic manipulation, chemists were taking a more intensive look at genetics, and engineers were pushing the boundaries of electronics with ever-smaller integrated circuits. In 1959, Nobel Laureate Richard Feynman proposed assembling machines out of individual atoms. “There’s plenty of room at the bottom,” he suggested. This concept was popularized by K. Eric Drexler, whose book *The Engines of Creation* was published in 1986.

So far, most of what nanotechnologists have accomplished can be divided into three categories:

1. New materials, such buckyballs, nanotubes, and nanowires,.
2. New tools to make those materials.
3. New devices made out of those materials; i.e., tiny molecular machines.

Recent advances in the third category include microelectromechanical systems (MEMs). These combine miniature mechanical devices on electronics, generally for applications involving sensors and controls; e.g., the microgyroscopes, or accelerometers, that send signals to deploy a car’s airbag during a collision. Nanotechnologists are now working on the next generation of devices, which are even tinier. These latest devices are known as nanoelectromechanical systems (NEMs).

Find Out More About...

Sensors and Control Systems

* Wikipedia—Topics on Sensors, Control Systems, and Distributed Control, and Wikibook on Control Systems (www.widipedia.org)
* “Nanotechnology Enabled Sensors: Possibilities, Realities, and Applications” (www.sensormag.com/articles/1103/22)
* Pacific Northwest National Lab—Sensing and Measurement Technology Research (www.pnl.gov/research/sensing.asp)
* Nanoelectricalmechanical Systems—(NEMs) http://physicsweb.org/articles/world/14/2/8)

* Smart Transducer Interface Standards (http;//ieee1451.nist.gov)
* "Nanosensors and Privacy" (www.earthsky.org/article/50772/christine-peterson-interview)

Nanotechnology

* Nanoscale Informal Science Education Network (http://qt.exploratorium.edu/nise-resources)
* Foresight Institute—Advancing Beneficial Nanotechnology (www.foresight.org)
* NASA Ames Center for Nanotechnology (www.ipt.arc.nasa.gov)
* U.S. Department of Energy nanotechnology efforts (www.science.doe.gov/nano/index.htm)

Information Geared for K–12 Students

* IEEE Virtual Museum (www.ieee-virtual-museum.org)
* National Nanotechnology Initiative Education Center (www.nano.gov/html/edu/home_edu.html))
* Nanooze—Nanotechnology Newsletter for Kids (www.nanooze.org)
* National Nanotechnology Infrastructure Network Education Portal (www.nnin.org/nnin_edu.html)
* University of Wisconsin Educator Resources on Nanotechnology (http://mrsec.wisc.edu/Edetc/IPSE/educators/index.html)
* How Stuff Works—Nanotechnology (http://science.howstuffworks.com/nanotechnology.htm)
* Nanozone (www.nanozone.org)

Key Words and Terms To Look Up

* Control Systems
* MEMs
* Nanocontrollers
* Nanosensors
* Nanotechnology
* NEMs
* Sensors
* Sensors and Controls
* Smart Buildings
* Smart Structures
* Structural Health Monitoring